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DETERMINING THE OPTIMAL FLOW
OF STUDENT SECTIONS AT THE
NAVAL GUIDED MISSILES SCHOOL

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THESIS

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NAVAL GUIDED MISSILES SCHOOL

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of Student Sections at the
Naval Guided Missiles School

by

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ABSTRACT

The problem of determining the capacity of a facility, such as the Fleet Ballistic Missile School, to train sections of students attending numerous distinct courses was considered as an optimizing problem, approachable in two phases. In the first phase a linear programming model was developed for determining the maximum number of courses and the optimal mix of these courses which the scheol can convene in one year. This model incorporates resource constraints, course content requirements, and the requirement to graduate a specified number of trainees over time. In the second phase, criteria were developed to sequence the Phase I optimal number of convenings of each course into an annual schedule. A heuristic approach was presented to test such a schedule for feasibility.

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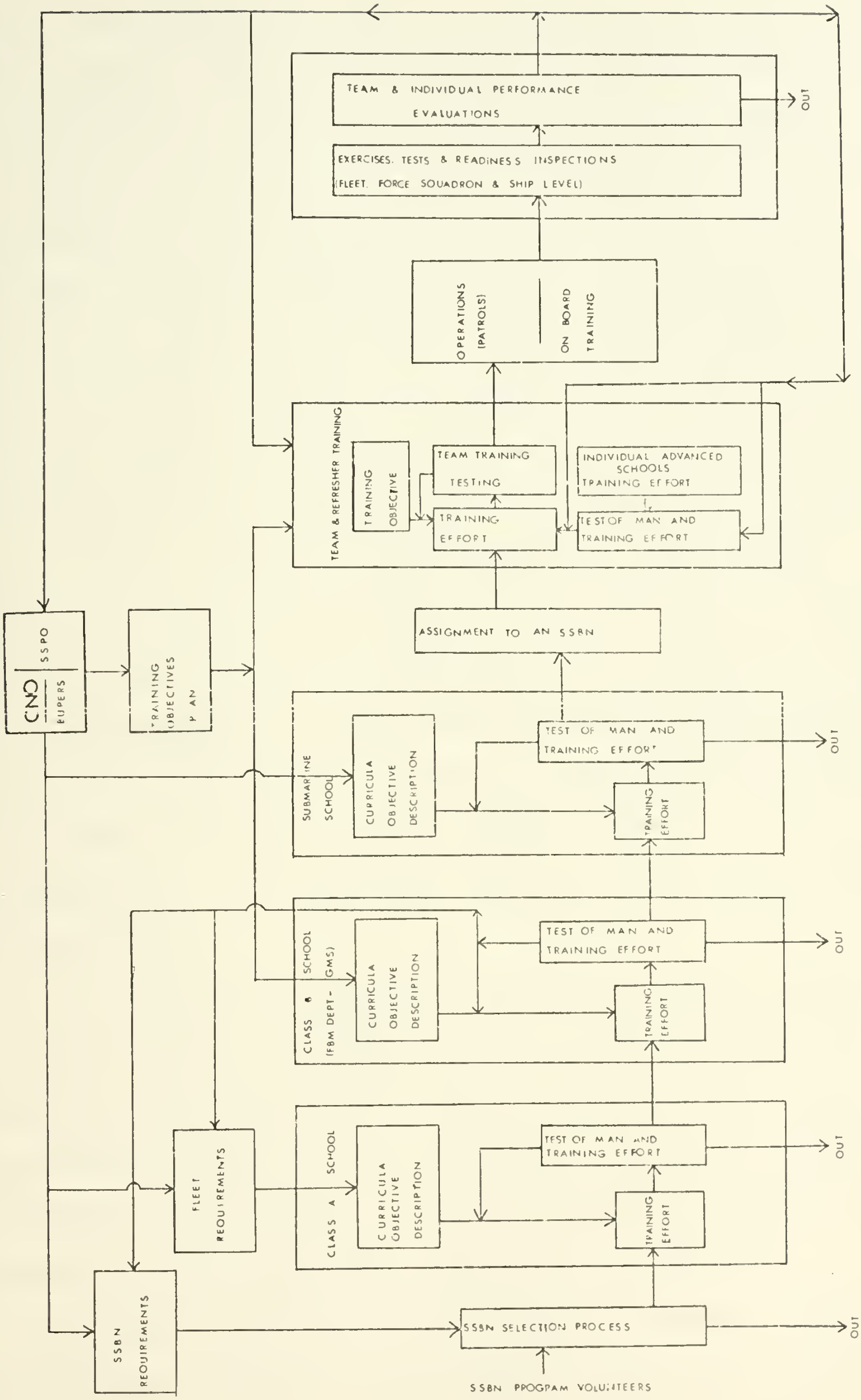
I. INTRODUCTION

A. ORGANIZATIONAL ENVIRONMENT AND GOALS

The Navy's Fleet Ballistic Missile (FBM) force is one of the key elements of the U. S. strategic forces which form the cornerstone of the nation's deterrent against nuclear attack. In order to carry out its mission effectively, the FBM force requires a steady flow of technical personnel, skilled in the operation and maintenance of the complex weapons delivery system installed aboard each submarine of the force.

The overall training concept for officers and enlisted technicians serving aboard the POLARIS and POSEIDON submarines of the FBM force involves several headquarters commands, schools, and operational echelons of the Fleet. The interrelationships involved are illustrated in Figure 1.

Fleet requirements for force levels of FBM submarines are promulgated by the Chief of Naval Operations (CNO), in consonance with the Five Year Defense Plan (FYDP) of the Department of Defense. Under CNO, the Bureau of Naval Personnel (BUPERS) determines fleet requirements for officer and enlisted personnel of all categories. Requirements for the number of FBM officers and technicians to be trained are passed down by BUPERS to the Navy Training Schools under its management control. At the Navy Department level the Director, Strategic Systems Project Office (SSPO), as Project



SSBN WEAPONS SYSTEM TRAINING CONCEPT: FLOW DIAGRAM

Figure 1

Manager for POLARIS/POSEIDON, is responsible for furnishing BUPERS with the requirements for properly trained personnel for the FBM force. Working in coordination with BUPERS, the Training Division of SSPO develops plans to ensure that FBM personnel receive adequate training in the technical knowledge and skills necessary to man the force effectively.

Enlisted personnel accepted for the FBM training program enter the training loop depicted in Figure 1 by attending a "Class A" school to acquire the basic skills pertaining to their rating. Following completion of the Class A school, these enlisted technicians will attend specialized courses concerning specific equipment or systems which they will operate or maintain upon reporting to their first FBM assignment. This training is conducted at the FBM Schools Department of the Naval Guided Missiles School at Dam Neck, Virginia. Newly selected officers for the FBM program may also enter the training loop at Dam Neck's FBM Department.

As the FBM force continues conversion of all vessels from the POLARIS to POSEIDON weapons system, so also the experienced personnel of the POLARIS vessels must receive conversion training in their specialties prior to manning a POSEIDON FBM submarine. This conversion training is also provided by the FBM Schools Department at Dam Neck.

The final school in the loop shown in Figure 1 is the Navy Submarine School in New London, Connecticut, where both

officer and enlisted personnel must undergo extensive basic qualification courses in submarine operations before reporting to a Fleet submarine. After successful completion of the Submarine School, trainees will report to an operating POLARIS or POSEIDON submarine in the Atlantic or Pacific Fleets for a tour of normally two years' duration.

Under the Training Objectives Plan prepared by SSPO and approved by CNO, curricula objective descriptions are passed down to the schools involved in the training effort. The schools prepare curricula tailored to fulfill these objectives; these curricula are approved by BUPERS. Testing of personnel and the training effort is carried on constantly at the various schools, aboard submarines on patrol, and during special test exercises and readiness inspections. The results of operational training and evaluations of the adequacy of prior training of personnel assigned to FBM submarines are reported to the Navy Department (specifically CNO, BUPERS and SSPO) via the operational chain of command, i.e., from the vessel's commanding officer, through the levels of squadron commanders, the Submarine Force and Fleet commanders. This feedback regarding adequacy of the training effort results in alterations to course curricula at training schools, as requested by SSPO and approved by BUPERS, when such changes are warranted.

The FBM Schools Department at Dam Neck accomplishes specified training objectives for: prospective Commanding Officers and Executive Officers; navigation and weapons

department heads and division officers; and for enlisted SSBN weapons systems technicians of the following ratings: Torpedoman (TM); Missile Technician (MT); Fire Control Technician (FT); and Electronics Technician (ET). At the present time the FBM Schools Department offers two types of courses for both officers and enlisted personnel: (1) initial courses, for personnel with no previous operational experience in FBM submarines and (2) conversion courses for personnel who have served aboard POLARIS vessels, but who are being ordered to POSEIDON vessels.

Organizationally, the FBM Schools Department consists of the Navigation and Weapons Schools Divisions, as shown in Figure 2. These divisions are staffed by maintenance and administrative personnel as well as instructors.

The physical plant of the FBM Schools Department represents a considerable investment of Government funds in terms of buildings, and their installed laboratory systems, which include working models of all weapons and navigational systems installed in the operational FBM submarines in the Fleet. At the time of this writing, the Navy's requirement for trained POSEIDON personnel is steadily increasing and the availability of sufficient laboratory facilities for this training program is of great concern to SSPO, BUPERS, and the Guided Missiles School. The addition of a POSEIDON laboratory to either the Navigation or Weapons Schools Division plant entails a considerable investment. A planning figure of $7.5 million applies to the procurement and

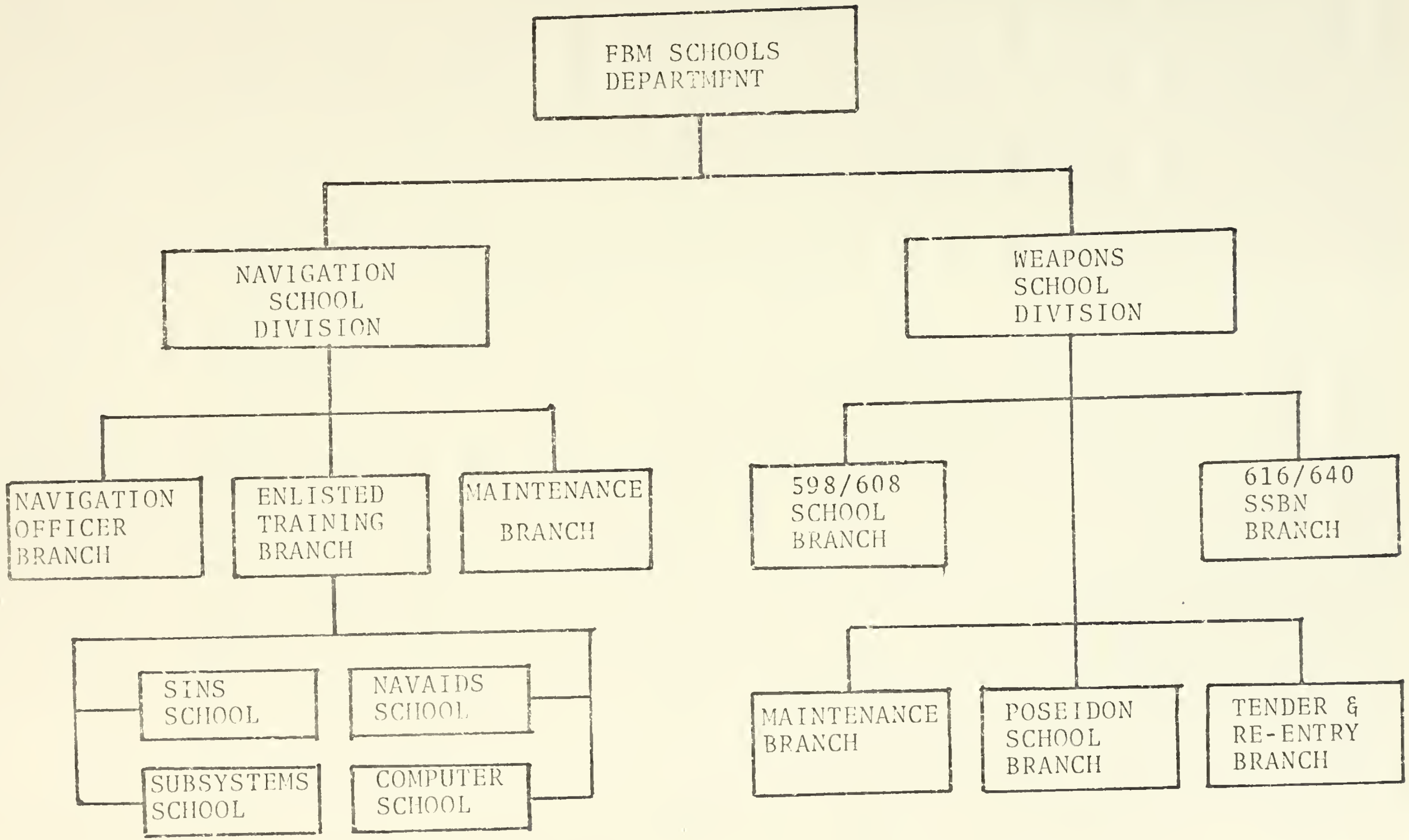


Figure 2. FBM SCHOOLS DEPARTMENT ORGANIZATION CHART

installation of equipment for one Navigation Technicians' (NAVTECH) laboratory. In the Weapons area, two types of laboratories exist, "systems labs" and "unit labs." The Weapons System lab comprises all components of the fire control and launching system of the missile (including a missile and launch tube). The unit laboratory consists of a subset of the components found in the systems lab. The existence of both kinds of laboratories permits a diversity of training operations to occur simultaneously. For example, personnel of one class can conduct a complete missile launch exercise on the systems lab equipment, while another group of students can be practicing the repair of faults that have been introduced into specific equipment in the unit labs as a test of trouble-shooting skill. Cost estimates of $15.5 million and $12.5 million apply to the procurement and installation of equipments required for the POSEIDON systems and unit labs, respectively. Further, the enlargement of an existing building, or the construction of a new building would cost an estimated $60 per square foot of lab space. An estimate of $22 per square foot applies to the alteration of existing laboratories. The floor space requirements for the NAVTECH, Weapons System, and Weapons Unit Laboratories are 2,000, 5,500, and 3,300 square feet respectively.

A large number of instructors is necessary to provide adequate training to FBM personnel. According to a report from the Commanding Officer, Guided Missiles School, to

BUPERS in August, 1969 [Ref. 8], the FBM Schools Department had an allowance of 258 instructors, of whom 172 were assigned to the Weapons School Division, and the remaining 86 were assigned to the Navigation Schools Division. These figures are a reasonable estimate of the present instructor strength of the FBM Schools Department.

The decision regarding what courses are required to fulfill the objectives of the training plan for the FBM force is the responsibility of SSPO. Curricular objective descriptions are forwarded through BUPERS to the training facilities responsible for instruction. Thus, the design and maintenance of the curricula, including formulation of course syllabi, is the responsibility of the FBM Schools Department at GMS Dam Neck for the Class B level courses. Quite frequently curricula are prepared by contractors, and reviewed and amended as necessary by instructors at GMS. BUPERS approves curricula designed by the training schools.

B. DEFINITION OF THE PROBLEM

With the conversion of FBM submarines from POLARIS to the POSEIDON missile system, there arises a need to ensure the proper quantities and mix of resources are available at the school to instruct all required personnel. The primary resources of interest are laboratory facilities of various types with their associated equipment, classrooms and instructors of each specialty pertinent to POSEIDON technical training. Given planning estimates from BUPERS of the number of

personnel of each type who require training over a specified time period, those responsible for the funding and operation of the school need to know what level and mix of resources is adequate to carry out the mission. Viewing the problem from another perspective, the school administration, and authorities at higher headquarters who control the funding, need a methodology for determining the maximum number of students that can be trained in the facility over a specified time period, subject to resource constraints. Here the constraints may be expressed in terms of the number of laboratories and installed equipment in house at a given time, or planned or expected number of such resources. With reference to instructor personnel, the constraint could be stated in terms of the number of instructors of each type on board at a specified time, or numbers indicating a proposed allowance, or an expected or average, on board count.

C. SCOPE OF THIS STUDY

We will resolve the problem described above in two stages. First, we will develop a methodology for determining the maximum number of convenings of each type of course taught at the school which can take place during a one-year period. These maxima will be constrained by a given annual level and mix of laboratory, classroom and instructor resources, as well as a specified minimum number of convenings of each course, and a specified curricular content.

Second, we will devise a method for obtaining a balanced sequencing of course convening dates to fit the annual optimal solution. Finally, we will develop testing procedures to determine under what circumstances such a schedule can, in fact, serve as a viable planning tool.

II. FORMULATION OF THE ANNUAL CONVENINGS MODEL

A. ASSUMPTIONS

The laboratory and classroom facilities in the GMS FBM Schools Department, i.e., the number of rooms or spaces available for class and laboratory utilization and the major components (systems) installed therein, are considered to be fixed in their availability in the short run (up to two years), but their availability is considered variable over a long range "planning horizon." As a consequence, a lag time of at least two years is assumed between the making of a decision to procure a new major laboratory system, and the completion of its installation and readiness for use.

Similarly, the authorized allowance of instructors is considered to be fixed in the short run. The actual on board count of instructors is considered variable in both the short and long run. In the short run, variations in the on board count may be caused by many factors (e.g., temporary additional duty, vacations, illness, accidents, etc.). In the long run, higher authorities can change the instructor allowance, depending on changes in the mission of the command, and the general level of military manpower authorizations.

It is assumed that no budget constraint affects the solution of the optimal student flow problem in the short run. However, in the long run, budget constrai ts--especially

of a capital nature--will be a factor bearing on the problem, in that the optimal student flow will be greatly affected by the level of funding available, or authorized, for construction of new laboratories and procurement of new equipment.

Course curricular requirements, as promulgated by BUPERS, are considered to be fairly inelastic in the short run, insofar as drastic changes in curricula require a fairly lengthy period of requirements determination, course development, and command and headquarters review and approval before they take effect. However, numerous minor changes to courses taught by the FBM Schools Department do take place with great frequency.

B. OBJECTIVE FUNCTION

In seeking to maximize the output of students from the FBM Schools Department, one must take note of the curricula taught in the Department, and find out how many courses are involved, and the resource demands of each. The Schedule of POLARIS and POSEIDON Courses for Fiscal Years 1970 and 1971 [Ref. 7] lists 39 distinct recurring courses for officers and enlisted men at the school. Most courses are designed for ships' company personnel; however, two short familiarization courses are presented to senior officers and DoD civilian personnel. As POSEIDON gradually supplants the POLARIS system, the need for POLARIS courses will be eliminated. At present, the school conducts 23 POSEIDON courses.

The school determines a class capacity for each course. Class capacities are a function of classroom size, laboratory size and equipment configuration, and availability of instructors for the various phases, or "blocks" of instruction required in each course. At present, only one section, or class of students commences a particular course at a given time.

The school and higher headquarters in the Navy Department consider it highly desirable to convene each class with a strength equal to its specified capacity for the obvious economies that can be realized from full utilization of facilities and instructors. Presently, course schedules are formulated to try to convene courses for enlisted technicians to closely follow their graduation from the Class A School. Unfortunately, the expected number of students arriving from the Class A School is a random variable because of factors such as the dropout rate at the Class A School and an uneven flow of students through that school during the course of a year. For example, the Navy receives its highest percentages of enlistees during the summer months since many young men commence their active duty promptly after high school graduation in June. The enlistment rate fluctuates at a much lower level during the remainder of the year.

The FBM Schools Department must face this problem of fluctuating student inputs with a fairly inelastic set of resources. The number of laboratory equipments and instructors on board cannot be changed rapidly to meet the fluctuating

student input rates. Hence, it is inescapable that some classes will convene at a strength less than their capacity during slack periods; conversely, during peak periods, some trainees may have to wait for some weeks after completing their Class A School training for commencement of their course at Dam Neck.

In view of the fluctuations in number of trainees throughout the year, a measure of the school's training capacity other than the maximum expected number of students graduated appears to be appropriate. The annual number of convenings of each course offered was chosen. This goal may be expressed algebraically as

$$\text{maximize } x_1 + x_2 + \ldots + x_n,$$

where the x_j's represent the number of convenings of each course which must be taught during the year.

C. CONSTRAINTS

1. Course Contact Hours

Approved curricular syllabi will specify the number of hours of recitations and testing in the classroom and demonstrations and practical work in the laboratories which are required for each course. From the figures one can determine the number of instructor contact hours required to teach one convening of a course. For example, for a course in the FBM Weapons Schools Department attended by a single student section, one instructor was required to

conduct recitations and testing in the classroom. For laboratory work a single section of students required direction by two to four instructors, depending on the complexity of the systems involved.

In determining a feasible schedule, a knowledge of the number of student-instructor contact hours required for one convening of every course is essential.

2. Instructor Resources

The availability of each type of instructor for teaching the required courses is a significant factor in assessing the capability of a school to carry out its assigned mission.

To determine the types of instructor functional specialties required at the school, one must know the organizational relationships. Figure 2 shows these relationships for the FBM Schools Department. In the Weapons Schools Division, for example, the instructor branches are designated by the type of vessel served, i.e., SSBN 598/608 Branch, SSBN 616/640 Branch, POSEIDON School Branch, and Tender and Reentry Systems School Branch. Each branch is divided into sections composed of (a) officer instructors, who teach courses concerning the overall weapons system to officer students, and (b) enlisted instructors of the Missile Technician, Torpedoman, and Fire Control Technician ratings, who instruct the enlisted students.

Sections of instructors are further subdivided into "blocks" of instructors, the block being the basic

organizational component. Instructors of a given block are specialists in certain subsystems of the weapons system in the functional area of their rating or specialty. For example, within the POSEIDON Weapons System Branch, the Mark 88 Fire Control System Section has an allowance of 21 enlisted instructors of the Fire Control Technician (FT) rating. This section is composed of four blocks of instructors, namely:

Weapons System Orientation	4 men
Digital Control Computer (DCC)	3 men
Peripheral Equipment/Magnetic Disk File	6 men
Fire Control Group	8 men.

Personnel of a given block will instruct a given sequence of topics for courses assigned to their branch. A section or block of instructors generally is responsible for teaching several distinct courses. For example, sections of instructors of the Navigation Schools Division teach from two to six distinct courses concerning the POLARIS/POSEIDON navigational systems.

In determining the number of courses a given block of instructors can teach per year, it is necessary to establish a value of the maximum expected number of student contact hours per year an instructor block can provide. In order to arrive at this figure, it is first necessary to determine the standard number of working manhours available per instructor per year. The norm used throughout the Navy is 52 productive 40-hour weeks, or 2,080 standard manhours.

In Ref. 2, BUPERS has established standards to indicate the amount of time that should be allowed for preparation for instruction and for duties related to instruction for each of the technical areas taught at Navy training schools. For weapons courses the preparation standards were set at 100% of an hour per contact hour of instruction, and 33% of a contact hour spent in related studies. For the navigation courses, the figures were 90% and 30% respectively. BUPERS, in specifying the methods by which a school would determine the number of instructors required in a given school, introduced a military duties factor, fixed at 20% of the sum of the instructor-student contact, preparation, and duties related to instruction factors (leave, liberty and other absences are included in the military duties factor).

By the application of the standards of Ref. 2, the average instructor at GMS, in the course of a 52-week, 2,080-manhour year, will be able to teach the following maximum number of contact hours. Let

CHC = Annual contact hour capacity of an instructor;

MD = Military duties factor;

P = Preparation hours required per contact hour;

R = Duties related to instruction hours per contact hour;

F = 1 + P + R = Total hours required in teaching, preparation, related duties per contact hour;

k = 1.00 - MD;

then

$$CHC = \frac{(k)(2080)}{F} . \tag{1}$$

For Weapons Schools Division instructors this capacity is $\frac{(0.8)(2080)}{(2.33)} = 714$ contact hours per year. For Navigation instructors, it is $\frac{(0.8)(2080)}{(2.2)} = 756$ contact hours per year. Unfortunately, the preparation for instruction factors do not differentiate between preparation for recitations or for laboratory sessions. Instead these factors are averaged for both laboratories and recitations for all types of courses in the technical area concerned.

The author used a different approach from the BUPERS standards in determining the number of contact hours a block of instructors can teach per year. A questionnaire was prepared and furnished to all sections of instructors at the FBM Schools Department. For each course, and for each block or phase of instruction within a course, the following information was requested:

a. block title;

b. number of lecture hours per convening;

c. number of lab hours per convening;

d. number of instructors used per class hour for lectures;

e. number of instructors used per class hour for labs;

f. number of instructors assigned to teach the given block.

From this information, the total number of contact hours required for one course convening was obtained by multiplying the number of instructors required for lectures (labs) by

the total number of lecture (lab) hours prescribed by the course syllabus. Table I is a hypothetical course information questionnaire of the type furnished the FBM Schools Department.

A second questionnaire, of which Table II is a hypothetical example, was prepared to obtain information about instructor workloads in order to determine the maximum number of contact hours per year a block of instructors could teach. For each block of instructors, the gross instructor availability time per year was obtained by multiplying the number of instructors per block by 2080 hours per year. This gross availability figure was then reduced by the sum of : (a) the number of hours spent annually by all instructors of the block on duties other than teaching or lesson preparation, and (b) the expected number of hours spent on leave, liberty and other absence during normal working hours per day by all instructors of the block (Christmas leave is included here). After these items were subtracted from the gross availability figure, the time remaining was considered to be available for the preparation for and instruction in all the courses taught by the block.

The ratio of hours of preparation to hours of instruction was obtained for classes and laboratories taught by the instructors of each block. Once this ratio was obtained, the number of contact hours available for the block per year was computed.

TABLE I. COURSE INFORMATION QUESTIONNAIRE (HYPOTHETICAL)

DOD CATALOG No. F-24-0038

COURSE TITLE Franistan Technician, Mark 1

1. Organizational component of instructors.

Division ARMAMENTS

Branch MISSILE

Section FRANISTAN

2. Course organization (list blocks of instruction in order)

BLOCK TITLE	CONSOLE	GUIDANCE	WARHEAD	MAINTENANCE
No. Lecture hrs.	50	70	110	90
No. Lab hrs.	20	35	45	30
Total (lec. & lab)	70	105	155	120
No. Instrs used per class hr.				
(a) Lectures	1	1	1	1
(b) Labs	4	5	5	4
No. of man hrs. used for each				
(a) Lectures	50	70	110	90
(b) Labs	80	175	245	120
(c) Total	130	245	355	210
No. of instructors that teach this block	7	10	12	9

Figures are to be entered for one course convening only.

TABLE I. COURSE INFORMATION QUESTIONNAIRE (HYPOTHETICAL)

(continued)

3. What is the minimum number of class convenings per year required by BUPERS for this course? 5

4. Do instructors teaching this course teach any other courses? Yes

   If so, show DoD Catalog No. & Course Title for each accitional course.

DoD Catalog No.	Course Title
F-24-0039	Franistan Technician, Mark 2
F-24-0040	Franistan Repairman

5. Lab Utilization Information

Lab Name	Lab No.	Usage (hours/course)
Console	FR-1	20
Control	FR-2	60
Missile	M-1	50

TABLE II. INSTRUCTOR INFORMATION QUESTIONNAIRE (HYPOTHETICAL)

Organizational location of instructors.

Division Armaments Branch Missile Section Franistan

BLOCK TITLE	CONSOLE	GUIDANCE	WARHEAD	MAINTENANCE
1. No. of instructors	7	10	12	9
2. Instr. availability (time/yr 2080 hrs/yr) x (1)	14,560	20,800	25,960	18,720
3. No. hours spent annually on collatoral duties (other than teaching or lesson preparation)	2,970	3,950	4,325	3,200
4. No. leave/liberty hrs per block annually (work days only)	1,792	2,560	3,072	2,304
5. Net hours available annually for teaching and lesson preparation (Line 2-(Line 3 + Line 4))	9,798	13,290	18,563	13,216
6. Ratio of hours of preparation to one hour of instruction	0.9	1.0	1.0	0.9
7. 1.0 + Line 6	1.9	2.0	2.0	1.9
8. Total block contact hours available annually (Line 5 ÷ Line 7)	5,157	6,645	9,282	6,956

Mathematically, the above process can be described by equation (2).

$$TBCH_i = \frac{(N)(2080 - C - L)}{G} \qquad (2)$$

where

$TBCH_i$ = Total contact hours available per year for block i,

N = Number of instructors in the block,

C = Number of hours spent annually per instructor on collatoral duties,

L = Number of hours spent annually per instructor on leave, liberty and other absence during working hours,

P = as defined in (1);

G = 1 + P.

In order to obtain a feasible schedule, the following relationship must hold for each block of instructors in the school:

$$\sum_{j=1}^{J} a_{ij}x_j \leq TBCH_i, \; i = 1, \ldots, I \;, \qquad (3)$$

where

x_j = jth course taught by the school, in units of number of convenings per year, j=1, ..., J;

a_{ij} = the number of student-instructor contact hours required by the course syllabus for the ith category of instructors for one convening of course j.

3. Laboratories

The availability of adequate laboratories to fulfill the instructional needs of the FBM Department at GMS was one of the primary factors motivating the present study. Within the FBM Department, the Navigation and Weapons Divisions each have separate laboratory facilities which represent all the significant weapons and navigation systems aboard current FBM submarines. As previously discussed, a given system is served by two types of laboratories: unit labs and systems labs. In order to determine the laboratory space requirements for all courses served, the author obtained the following information for each type of laboratory serving the POSEIDON courses:

a. type of laboratory (i.e., systems or components involved) and location;

b. number of facilities of each lab type;

c. courses served;

d. required usage for each course, in hours per one convening of the course;

e. percentage of down time, when the facility would be undergoing maintenance, repair, or conversion.

An annual gross availability of 6,000 hours for each laboratory space of a given lab type was assumed. This figure was calculated on the basis that laboratories could be used up to 24 hours a day, five days a week, for the 50 weeks of the year that courses are conducted at GMS. Mathematically,

lab type availability could be expressed as follows:

$$A_k = 6000N(1.00-D), \tag{4}$$

where

A_k = availability of lab type k, hours per year, $k = 1, \ldots, K$;

N = number of labs of the given type;

D = percentage down time.

In order to permit the construction of a feasible schedule of courses for the school, the following inequality must be satisfied for each laboratory type:

$$\sum_{j=1}^{J} d_{kj} x_j \leq A_k, \quad k = 1, \ldots, K, \tag{5}$$

where

d_{kj} = the number of hours of usage required for the kth type of laboratory per one convening of course k.

4. Classrooms

The availability of classrooms of various types can be a restriction on the maximum number of convenings attainable per year. Furthermore, in the interest of efficiency, a school administration may desire to match classrooms with varying seating capacities with class sections of varying student strength. If the number of classrooms of various sizes is a binding constraint, the following procedure should lead to efficient classroom utilization in formulating

the maximum course capacity problem:

Divide the inventory of classrooms by size category. For example, a school with 50 classrooms might divide them into categories by maximum seating capacity as follows:

Category I	capacity of 10 or less;
Category II	capacity of 11 to 20;
Category III	capacity of 21 to 30;

assuming that no classes of more than 30 students are required.

Beginning with courses with the smallest student capacity, specify that the number of classroom hours for one convening of the course times the number of convenings of the course per year, summed over all courses of this section size category, must be less than or equal to the number of classroom hours available for classrooms of this size category. Next, set up a similar inequality for courses of 11 to 20 students and the available classrooms of category II. Finally, do likewise for courses and classrooms of category III.

As was the case with laboratories, three shift availability (five days per week, 24 hours a day, 50 weeks a year) was assumed for classrooms for recitations and testing. Mathematically, classroom type availability can be expressed as follows:

$$V_{\ell} = 6000N(1.00-D) \qquad (6)$$

where

V_ℓ = availability of classrooms for type ℓ, hours per year, $\ell = 1, \ldots, L$;

N = number of classrooms of the given type;

D = percentage down time.

The following relationship between availability and the requirements of each course syllabus must hold for each type of classroom in order to permit the construction of a feasible schedule of courses for the school:

$$\sum_{j=1}^{J} e_{\ell j} x_j \leq V_\ell, \quad \ell = 1, \ldots, L, \tag{7}$$

where

$e_{\ell j}$ = the number of hours of usage required for the ℓth type of classroom.

5. Fleet Requirements for Graduates

The requirements of the Submarine Forces for graduates of the FBM Schools Department are determined by BUPERS over a five-year planning horizon. These requirements are determined for each month in the planning period by officer category and NEC (Navy Enlisted Classification) code for the various technical ratings. Requirements by NEC are further broken down by the various systems operated and maintained on different classes of FBM submarines by personnel of a given rate. In attempting to meet the time-phased requirements for personnel of a given category, BUPERS tasks the training facilities concerned with convening a specified

number of courses of each type during a year. Formulation of an annual schedule of class convenings is the responsibility of the school. In this scheduling effort, it is desired to balance the capacity of the school's resources over time against the projected time-phased requirements for trained personnel, as well as graduation dates for the predecessor Class A schools, where applicable.

Mathematically, a feasible schedule of course convenings at the school must satisfy the following relationship to account for the requirement that each course be taught at least a specified number of hours annually:

$$x_j \geq B_j, \; j = 1, \ldots, J, \tag{8}$$

where

B_j = the minimum number of convenings of course j which higher authority directs the school to convene annually.

D. COMPLETE FORM OF THE MODEL

Having defined the objective function and resource constraints in terms of instructor, laboratory, and classroom resources which apply to this problem, and noting that higher authority requires that a specified minimum number of convenings of each course be taught annually, we have a mathematical model that will allow us to obtain the annual maximum feasible number of convenings of the courses taught

by a school. The complete model has the following form:

$$\text{Maximize } x_1 + x_2 + \ldots + x_j,$$

Subject to

$$\sum_{j=1}^{J} a_{ij} x_J \leq TBCH_i, \text{ for } i = 1, 2, \ldots, I,$$

$$\sum_{j=1}^{J} d_{kj} x_J \leq A_k, \text{ for } k = 1, 2, \ldots, K, \tag{9}$$

$$\sum_{j=1}^{J} e_{\ell j} x_J \leq V_\ell, \text{ for } \ell = 1, 2, \ldots, L,$$

$$x_J \geq B_j, \text{ for } j = 1, 2, \ldots, J.$$

This model may be solved by the simplex method of linear programming. The major computer manufacturers have devised software systems containing this solution technique. For example, IBM has developed its Mathematical Programming System (MPS/360), while General Electric has made available its remote terminal-oriented LINEP$, LINPR$ and SENSI$ packages. References 1 and 2 are user's guides for the IBM and GE systems, respectively.

E. A NUMERICAL EXAMPLE

The following highly simplified numerical example demonstrates the application of the general model. Questionnaires prepared in the Navigation Schools Division indicate that the following courses pertaining to POSEIDON are taught:

Course Number	Course Title
1	Navigation Officer (POSEIDON)
2	Navigation Officer (POSEIDON Conversion)
3	Ship's Inertial Navigation System (SINS) Technician, Mark 2
4	SINS Technician, Mark 2 (Conversion)
5	Navigation Aids (NAVAIDS) Technician (Conversion)
6	NAVAIDS Technician, Maintenance
7	NAVDAC Technician, Mark 2 Mod 4 (SDC Mark 2)
8	NAVDAC Technician, Mark 2 Mod 4 (SDC Mark 3)
9	Central Navigation Computer Technician

1. The Objective Function

The objective function is the maximization of the number of convenings of these nine courses over one year, i.e.,

$$\text{Maximize } z = x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8+x_9,$$

where x_j is defined as the annual number of convenings of course j.

2. Constraints for the Availability of Instructor Staff

Fourteen distinct categories (or blocks) of instructors teach the nine courses of this example. The number of instructor-student contact hours required for one convening of each of the courses was obtained for each in tructor

category. The designations of each block of instructors are listed below.

Block Number	Instructor Block Title
1	Navigation Officers' Branch
2	SINS Computer
3	SINS System
4	SINS Conversion
5	BQN-3 NAVAIDS
6	WPN-3
7	BRN-3
8	BSQ-2 (Conversion) and Mark XII
9	NAVDAC (Type II)
10	NAVDAC (SDC)
11	NAVDAC (General)
12	NCC
13	Central Navigational Computer
14	Central Navigational Computer (Interface)

Application of equation (2) yielded the total contact hours of availability per year for each category of instructors. The coefficients of the constraint inequalities (3) concerning instructor availability are shown in Table III.

3. Constraints for the Availability of Laboratory Facilities

Eight distinct types of laboratories serve the nine courses of this example. The number of hours of required utilization of each lab type for each of the nine courses

TABLE III. COURSE CONTACT HOUR REQUIREMENTS AND ANNUAL BLOCK CONTACT HOUR AVAILABILITIES

	Course Number									
Block Number	1	2	3	4	5	6	7	8	9	$TBCH_i$
1	562	189								2602
2			897							9914
3			1018							11488
4				720						4925
5					140	140				7306
6						175				3934
7						525				6744
8					35	70				3934
9							140	140		1101
10							745	770		3343
11							995	995		4065
12							255	255		1101
13									1715	4615
14									1225	3493

was obtained from a questionnaire similar to Table I. The designations of each type of laboratory are listed below.

Type Number	Laboratory Type Designation
1	NT1 (Navigational Technician Lab. No. 1)
2	NT2
3	NT3
4	NT4
5	NT5
6	AN-BRN-3
7	AN-WPN-3
8	NT6

The total hours of availability per year for each laboratory type were determined by applying equation (4). A 20% down-time factor was reported for all lab types in the data, resulting in the net availability of all lab types being 4800 hours per year. Table IV shows the coefficients of the constraint inequalities (5) applicable to laboratory availability.

TABLE IV. COURSE REQUIREMENTS AND ANNUAL HOURS OF AVAILABILITY OF LAB TYPES

Type Number	1	2	3	4	5	6	7	8	9	A_k
4	296	153								4800
1			300	54			131	131		4800
2			90	30		25	149	49		4800
3			276	180	44	44				4800
6						58				4800
7						187				4800
5								105		4800
8									378	4800

4. Constraints on Classroom Availability

For the purposes of this example, classroom availability was not considered to be a binding constraint on student throughput. As of late 1970, the FBM Department at GMS had 57 classrooms under its jurisdiction. Assuming an availability of three-shift operations (24 hours per day) for 50 weeks, the Department had a gross availability of 68,400 classroom hours per year for recitations and testing. While most of the classrooms were in use during the daytime shift, a review of the present manual scheduling procedures indicated that in a typical week less than 10% of the classrooms were utilized during the evening and night shifts.

5. Constraints of Lower Bounds on Number of Required Convenings

Data concerning the minimum annual number of convenings required by BUPERS or the school command were obtained from questionnaires similar to Table I. The following inequality constraints based on (8) apply for each of the nine courses:

$$x_1 \geq 2 \qquad x_4 \geq 6 \qquad x_7 \geq 2$$

$$x_2 \geq 4 \qquad x_5 \geq 3 \qquad x_8 \geq 2$$

$$x_3 \geq 11 \qquad x_6 \geq 8 \qquad x_9 \geq 2.$$

6. Solution

The model was solved by the linear program procedure of the IBM Mathematical Programming System/360 (MPS/360). The solution is presented in Table V in units o convenings

per year. Fractional values indicate that a particular course has convened, but has not yet been completed at the end of the year.

TABLE V. SOLUTION OF THE ANNUAL CONVENINGS MODEL FOR THE NAVIGATION DIVISION EXAMPLE

Course Number	Optimal Convenings
1	2.0
2	7.8
3	11.0
4	6.0
5	3.0
6	12.5
7	2.1
8	2.0
9	2.7
Total	49.1

III. FORMULATION OF COURSE SEQUENCING RULES AND A MODEL FOR CHECKING SCHEDULE FEASIBILITY

A. CONSTRUCTING A FEASIBLE SCHEDULE FROM THE ANNUAL CONVENINGS MODEL

1. Planning Considerations

The model developed above can be useful to a school administration and higher headquarters only if a feasible schedule of course convenings can be developed which accommodates all the convenings of every course as indicated by the optimal solution to the linear program.

Numerous papers and articles in the computer programming and operations research literature have dealt with scheduling problems, including the scheduling of instructors, students and classrooms in a high school or university environment. However, the author was unable to locate any published works about procedures to schedule numerous courses of a widely varying duration, with a great disparity of requirements among courses for instructors and laboratories. Therefore, a heuristic approach was taken to determine if an annual schedule of course convening dates could be developed that would not overtax the resources of the school at any time during the year. The following steps were taken in this approach.

The entire constraint matrix was examined to determine whether or not the set of all courses trea ed by the

model could be partitioned into subsets, such that all of the courses in a given subset were the only courses utilizing a given subset of resources, e.g., instructors and laboratories of given types. In a fairly large training facility it is likely that certain courses or groups of courses will require relatively few different types of instructors and laboratories in the school.

After examining all courses and all constraints, the courses were listed in groupings which were independent of one another with respect to the types of resources required.

The next step was the preparation of an annual planning calendar for each subset of courses sharing all of a given subset of resources. All courses in the subset were placed on the annual planning chart in such a way that convening dates for each session of a given course were as evenly distributed throughout the year as possible. In constructing the annual calendar, the optimal number of convenings of each course from the linear programming model must be scheduled.

An interval between class convening dates of a given course can be roughly determined by dividing the number of working weeks per year (50 at GMS) by the number of convenings of the course at optimum (x_j^*). Thus, if we define the interval between convening dates for the jth course of S_j, we have

$$S_j = \frac{50}{x_j^*} \quad . \tag{10}$$

If S_j is an integer, successive convenings of course j will be convened S_j weeks apart. Since courses in this school are designed to commence at the beginning of a week and continue for an integer-valued number of weeks, if S_j is not an integer, we define $[S_j]$ as the largest integer contained in S_j and convene successive classes either $[S_j]$ or $[S_j]+1$ weeks apart. For example, if $S_j = 6.3$, new classes in course j would be convened at intervals of six or seven weeks. In this case, we would convene two successive classes of course j six weeks apart and a third course seven weeks thereafter, continuing this pattern throughout the year to achieve a "balanced" schedule for this course.

2. <u>A Planning Calendar for the Navigation Division Example</u>

Using the planning considerations discussed above, an annual schedule of convening dates was developed for the optimal number of sections of the nine POSEIDON courses using the solution of the example in Chapter II as a point of departure.

First the courses were partitioned into the smallest subsets sharing common resources. By inspection of Tables III and IV we could identify three subsets of courses which shared no resources with any other courses outside the subset.

Group One (the first subset) comprised the two POSEIDON officer Navigation courses (courses 1 and 2). Table III shows that these two courses share instructor block 1 (the Navigation Officers' Branch), while Table IV indicates that these courses share the NT4 Lab. These two courses

use no other resources nor do their instructors or laboratory serve any other courses.

Group Two consisted of a single course, Central Navigation Computer Technician (course 9). Table III shows that this course is taught by instructor blocks 13 and 14, while Table IV indicates that the only lab serving the course is the NT6 lab.

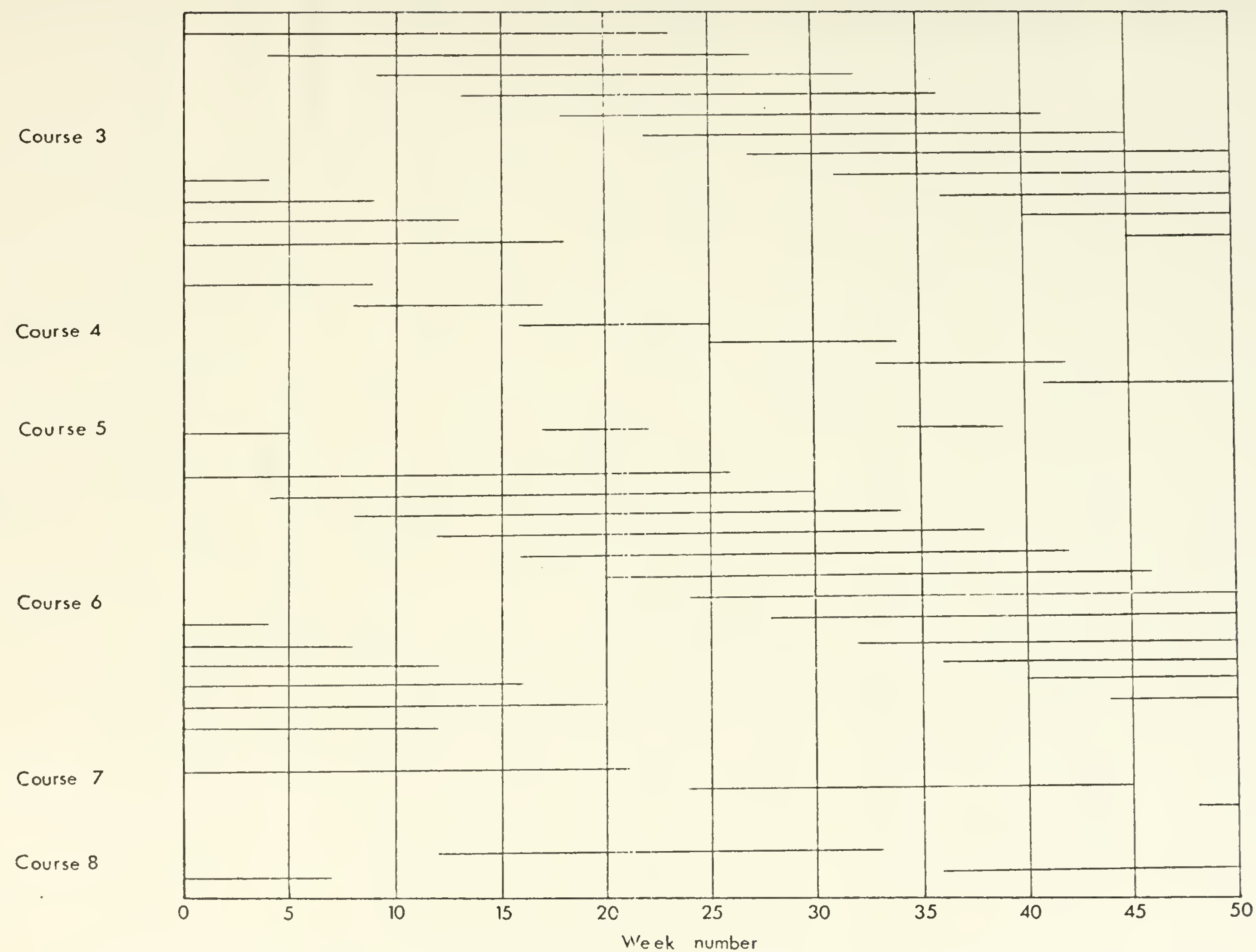
A study of Tables III and IV shows that no further partioning of the constraint matrix is possible as there is some overlap of both instructor and laboratory requirements among the six remaining courses. This group of six courses was designated as Group Three.

Figure 3 is an annual schedule of convening dates for the courses of Group Three. In the development of this schedule, the number of classes of each course in house during a given week was kept as close to a constant value as possible throughout the year. For each course only two adjacent integer values of sections in house during any week were used in this schedule, i.e., x_3:(5,6); x_4:(1,2); x_5:(0,1); x_6:(6,7); x_7:(0,1); x_8:(0,1).

B. TESTING THE ANNUAL SCHEDULE OF CONVENINGS FOR FEASIBILITY

1. <u>A Procedure for Comparing Average Weekly Resource Requirements and Availabilities</u>

An annual schedule of course convening dates, prepared using the planning considerations of Part A above, should be tested for feasibility. In this conte t,



AN ANNUAL SCHEDULE OF CLASS CONVENINGS FOR GROUP THREE COURSES OF THE NAVIGATION DIVISION EXAMPLE

Figure 3

feasibility may be equated with ensuring the convening of the optimal number of courses during the year without overtaxing the available resources beyond their capacity <u>at any time</u> during the year.

In making our test of feasibility, we examined the demands of the annual schedule on a weekly basis, considering a schedule to be feasible if the school had sufficient resources (instructors, labs, classrooms) available each week to meet the planned workload. The following procedure was developed for that test:

a. Find the total number of sections of each course in progress in the school for each week of the year. Then determine the frequency with which each given pattern of weekly convenings of all courses occurs. If the number of courses in a subset is small and a well balanced schedule of classes is prepared for the year, certainly weekly patterns, or configurations, of numbers of sections in house are likely to recur. If this is the case, the succeeding calculations need to be performed only once for each pattern instead of separately for each week of the year.

b. Determine the weekly requirements for each resource in the constraint set for one convening of each course served by that resource. For a category of instructors,

$$Y_j = \frac{H_j}{CL_j} , \tag{11}$$

where

Y_j = the weekly requirement, in contact hours, for the instructor category for one convening of course j,

H_j = the total number of instructor contact hours of the category required for one convening of course j,

CL_j = the length of course j, in weeks.

Similarly, for a given type of laboratory,

$$W_j = \frac{L_j}{CL_j} , \qquad (12)$$

where:

W_j = the weekly requirement, in hours, for the laboratory type for one convening of course j,

L_j = the total number of hours of use of the laboratory type for one convening of course j,

and CL_j is as defined above.

c. Determine the average weekly availability of each resource by dividing the annual availability figures used in the linear program model by the number of weeks in the year that the school conducts courses (50 at GMS). For the ith category of instructors, this quantity is described by equation (13).

$$WCA_i = \frac{TBCH_i}{50} , \qquad (13)$$

where

WCA_i = weekly contact hours available for the ith category of instructors,

$TBCH_i$ = total contact hours available per year for instructor category i.

Similarly, for the kth laboratory type, weekly availability may be described by equation (14).

$$WLA_k = \frac{A_k}{50} , \qquad (14)$$

where

WLA_k = weekly hours of availability for instruction of lab type k,

A_k = availability of lab type k, hours per year.

d. Examine each weekly pattern in the annual schedule with respect to each category of resources serving the courses in the subset. We seek to determine whether or not the requirements for resources exceed their average weekly availabilities. For an instructor category, if average weekly contact hour requirements do not exceed average weekly availabilities, inequality (15) will hold.

$$\sum_j Y_j u_j \leq WCA_i , \qquad (15)$$

where

u_j = the number of sections of course j in house during a given week.

Similarly, for laboratory types, if average weekly usage does not exceed average weekly availability, inequality (16) will be satisfied.

$$\sum_j W_j u_j \leq WLA_k \ . \qquad (16)$$

If inequalities (15) and (16) are satisfied for all weekly schedule patterns for all resources throughout the year then the annual planning calendar may be considered to be a feasible schedule of the optimal number of courses obtained from the solution of the linear programming model.

2. <u>An Example: Group Three Courses, Navigation Division</u>

The procedure described above was used to test the schedule of the Group Three courses of the Navigation Division shown in Figure 3 for feasibility. Table VI indicates the total number of sections of each course in progress in the school for each week of the year. For this schedule, 16 distinct patterns of weekly convenings occurred. These were labeled A through P in Table VI.

Next, the weekly requirements for contact hours for each category of instructors were determined for all of the courses of Group Three, using equation (11). Similarly, the weekly requirements for laboratory utilization, in terms of hours required for each type of lab, were determined for all courses of Group Three, applying equation (12). The results of these computations are shown in Table VII. Then weekly contact hour availabilities for each category of instructors

TABLE VI. WEEKLY PATTERNS OF NUMBER OF COURSES IN PROGRESS FOR AN ANNUAL SCHEDULE OF GROUP THREE COURSES OF THE NAVIGATION DIVISION EXAMPLE

WK	Course No.						Pattern	WK	Course No.						Pattern
	3	4	5	6	7	8			3	4	5	6	7	8	
1	5	1	1	7	1	1	A	26	5	1	0	7	1	1	B
2	5	1	1	7	1	1	A	27	5	1	0	6	1	1	E
3	5	1	1	7	1	1	A	28	5	1	0	6	1	1	E
4	5	1	1	7	1	1	A	29	5	1	0	7	1	1	B
5	5	1	1	7	1	1	A	30	5	1	0	7	1	1	B
6	5	1	0	7	1	1	B	31	5	1	0	6	1	1	E
7	5	1	0	7	1	1	B	32	6	1	0	6	1	1	K
8	5	1	0	7	1	0	C	33	5	1	0	7	1	1	B
9	5	2	0	7	1	0	D	34	5	1	1	7	1	0	L
10	5	1	0	7	1	0	C	35	5	1	1	6	1	0	M
11	5	1	0	7	1	0	C	36	5	1	1	6	1	0	M
12	5	1	0	7	1	0	C	37	5	1	1	7	1	1	A
13	5	1	0	7	1	1	B	38	5	1	1	7	1	1	A
14	5	1	0	6	1	1	E	39	5	1	0	6	1	1	E
15	5	1	0	6	1	1	E	40	5	1	0	6	1	1	E
16	5	1	0	6	1	1	E	41	6	1	0	7	1	1	N
17	5	2	0	6	1	1	F	42	5	2	0	7	1	1	0
18	5	1	1	6	1	1	G	43	5	1	0	6	1	1	E
19	5	1	1	6	1	1	G	44	5	1	0	6	1	1	E
20	5	1	1	6	1	1	G	45	5	1	0	7	1	1	B
21	5	1	1	6	1	1	G	46	5	1	0	7	0	1	P
22	5	1	1	6	0	1	H	47	5	1	0	6	0	1	J
23	6	1	0	6	0	1	I	48	5	1	0	6	0	1	J
24	5	1	0	6	0	1	J	49	5	1	0	6	1	1	E
25	5	1	0	7	1	1	B	50	5	1	0	6	1	1	E

TABLE VI. WEEKLY PATTERNS OF NUMBER OF COURSES IN PROGRESS FOR AN ANNUAL SCHEDULE OF GROUP THREE COURSES OF THE NAVIGATION DIVISION EXAMPLE

(Continued)

Frequency of Occurrence of Weekly Schedule Patterns

Pattern	Frequency	Pattern	Frequency	Pattern	Frequency
A	7	F	1	L	1
B	9	G	4	M	2
C	4	H	1	N	1
D	1	I	1	O	1
E	12	J	3	P	1
		K	1		

TABLE VII. WEEKLY RESOURCE REQUIREMENTS FOR ONE CONVENING OF GROUP THREE COURSES OF THE NAVIGATION DIVISION EXAMPLE

Instructor Block	Course	Instructor Requirements H_j	CL_j	Y_j
SINS Computer	3	897	23	39.00
SINS System	3	1018	23	44.20
SINS Conversion	4	720	9	80.00
BQN-3 NAVAIDS	5	140	3	46.67
BQN-3 NAVAIDS	6	140	26	5.38
WPN-3	6	175	26	6.73
BRN-3	6	525	26	20.19
BSQ-2(C)/Mark XII	5	35	3	11.67
BSQ-2 (C)/Mark XII	6	70	26	2.69
NAVDAC (Type II)	7	140	21	6.67
NAVDAC (Type II)	8	140	21	6.67
NAVDAC (SDC)	7	745	21	35.48
NAVDAC (SDC)	8	770	21	36.67
NAVDAC (General)	7	995	21	47.38
NAVDAC (General)	8	995	21	47.38
NCC	7	255	21	12.14
NCC	8	255	21	12.14

Laboratory Type	Course	Laboratory Requirements L_j	CL_j	W_j
NT1	3	300	23	13.04
NT1	4	54	9	6.00
NT2	3	90	23	3.91
NT2	4	30	9	3.33
NT2	6	25	26	0.96
NT2	7	149	21	7.10
NT2	8	49	21	2.33
NT3	3	276	23	12.00
NT3	4	180	23	7.83
NT3	5	44	5	8.80
NT3	6	44	26	1.69
NT5	8	105	21	5.00
AN-BRN-3	6	58	26	2.23
AN-WPN-3	6	187	26	7.19

and weekly hours of availability of each lab type were obtained by applying equations (13) and (14) respectively. These values appear in Table VIII.

Following these computations, each resource was tested for feasibility over all weekly schedule patterns by applying inequality (15) for instructor categories, and inequality (16) for laboratory types.

a. Laboratory Requirements and Availabilities

Tables IX, X and XI show results of feasibility tests for lab types NT1, NT2 and NT3 respectively. For lab type NT1, which serves courses 3 and 4, the 16 patterns of the overall schedule reduce to three distinct combinations of sections in progress in any week. In all cases inequality (16) is satisfied; hence we may conclude that the schedule is feasible with respect to availability of lab type NT1. In the case of lab type NT2, which serves five courses, 12 distinct combinations of the 16 patterns emerged. However, computations for feasibility could be limited to a relatively few dominant patterns. For courses, 3, 4, 6, 7 and 8, the pattern (6, 1, 7, 1, 1) obviously dominates (6, 1, 6, 1, 1) in that the former pattern requires more convenings of course 6 than the latter. Inequality (16) is satisfied for all weekly schedule patterns for the NT2 lab type. Similarly, an examination of the dominant patterns for the NT3 lab type in Table XI shows that inequality (16) is satisfied in every case.

TABLE VIII. AVERAGE WEEKLY AVAILABILITIES OF RESOURCES SERVING GROUP THREE COURSES OF THE NAVIGATION DIVISION EXAMPLE

Instructor Availabilities

Block Title	WCA_i	Block Title	WCA_i
SINS Computer	198.28	BSQ-2 (C)/Mark XII	78.68
SINS System	229.76	NAVDAC (Type II)	22.02
SINS Conversion	98.50	NAVDAC (SDC)	66.86
BQN-3 NAVAIDS	146.12	NAVDAC (General)	81.30
WPN-3	78.68	NCC	22.02
BRN-3	134.88		

Laboratory Availabilities

Lab Type	WLA_k	Lab Type	WLA_k
NT1	96.00	AN-BRN-3	96.00
NT2	96.00	AN-WPN-3	96.00
NT3	96.00		
NT5	96.00		

TABLE IX.a. WEEKLY PATTERNS AND AVERAGE WEEKLY NT1 LAB TYPE REQUIREMENTS PER COURSE

Courses served	Weekly patterns, convenings in progress, u_j			W_j, Hours per week
3	5	5	6	13.04
4	1	2	1	6.00

TABLE IX.b. FEASIBILITY TEST OF GROUP THREE NAVIGATION COURSE SCHEDULE WITH NT1 LABORATORY TYPE AVAILABILITY

Weekly Pattern	W_3u_3	W_4u_4	$\sum_{3}^{4} W_ju_j$	Average Weekly slack a/
(5,1)	65.25	6.00	71.25	24.75
(5,2)	65.25	12.00	77.25	18.75
(6,1)	78.30	6.00	84.30	11.70

a/ Average weekly availability (hours), Lab Type NT1: $WCA_1 = 96.00$

TABLE X.a. WEEKLY PATTERNS AND AVERAGE WEEKLY NT2 LAB TYPE REQUIREMENTS PER COURSE

Courses Served	Weekly patterns, convenings in progress, u_j												W_j, Hours per week
3	5	5	5	5	5	5	5	5	5	6	6	6	3.91
4	1	1	1	1	1	1	2	2	2	1	1	1	3.33
6	6	6	6	7	7	7	6	7	7	6	6	7	0.96
7	0	1	1	0	1	1	1	1	1	0	1	1	7.10
8	1	0	1	1	0	1	1	0	1	1	1	1	2.33

TABLE X.b. FEASIBILITY OF GROUP THREE NAVIGATION COURSE SCHEDULE WITH NT2 LABORATORY TYPE AVAILABILITY

Weekly Pattern a/	$W_j u_j$					$\sum W_j u_j$	Average Weekly slack b/
	j=3	j=4	j=6	j=7	j=8		
(5,2,7,1,1)	19.55	6.66	6.72	7.10	2.33	42.36	53.64
(6,1,7,1,1)	23.46	3.33	6.72	7.10	2.33	42.94	53.06

a/ The patterns (5,2,7,1,1) and (6,1,7,1,1) dominate all others with respect to lab hour requirements. Hence, only these two patterns were tested using Inequality (16).

b/ Average weekly availability (hours), Lab Type NT2: WCA_2 = 96.00

TABLE XI.a. WEEKLY PATTERNS AND AVERAGE WEEKLY NT3 LAB TYPE REQUIREMENTS PER COURSE

Courses Served	Weekly patterns, convenings in progress, u_j	W_j, Hours per week
3	5 5 5 5 5 5 6 6	12.00
4	1 1 1 1 2 2 1 1	7.83
5	0 0 1 1 0 0 0 0	8.80
6	6 7 6 7 6 7 6 7	1.69

TABLE XI.b. FEASIBILITY TEST OF GROUP THREE NAVIGATION COURSE SCHEDULE WITH NT3 LABORATORY TYPE AVAILABILITY

Weekly Pattern a/	$W_j u_j$				$\sum W_j u_j$	Average weekly slack b/
	j=3	j=4	j=5	j=6		
(5,1,1,7)	60.00	7.83	8.80	11.83	88.46	7.54
(5,2,0,7)	60.00	15.66	0.00	11.83	87.49	8.51
(6,1,0,7)	72.00	7.83	0.00	11.83	91.66	5.34

a/ The patterns (5,1,1,7), (5,2,0,7), and (6,1,0,7) dominate all others with respect to lab hour requirements. Hence, only these three patterns were tested using Inequality (16).

b/ Average weekly availability (hours), Lab Type NT3: WCA_3 = 96.00

Only one computation is required to apply inequality (16) to lab types NT5, AN-BRN-3 and AN-WPN-3, since each of these labs serves only one course. Hence, all that is required is to set u_j equal to the largest number of classes of these courses in house in inequality (16). As Table XII indicates, the annual schedule is feasible with respect to each of these lab types. In summary, sufficient laboratory facilities are available to permit the scheduling of the optimal number of convenings of all courses of Group Three

b. Instructor Requirements and Availabilities

The availability of contact hours for each instructor category was compared with the requirements of the schedule. Each block of instructors in this example teaches either one or two courses. Therefore, only a few scheduling patterns need testing in each instance.

(1) <u>SINS Computer Instructors</u>. This group instructs only course 3 (SINS Technician, Mark 2), for which the maximum number of sections in progress at any time during the year is six. This value occurs three weeks of the year. Applying inequality (15), we have

$Y_j u_j$ = (39.00)(6) = 234 > 198.28 contact hours available.

This indicates a requirement for 35.72 instructor contact hours per week above the average availability figure for three weeks of the year. For the remaining 47 weeks of the year, five courses per week are in progress for which

TABLE XII. FEASIBILITY TEST OF GROUP THREE NAVIGATION COURSE SCHEDULE WITH LABORATORY TYPES NT5, AN-BRN-3, AND AN-WPN-3

Lab Type	Course served a/	Maximum $W_j u_j$ b/	Average Availability hours/week	Average weekly slack
NT5	8	5.00	96.00	91.00
AN-BRN-3	6	15.61	96.00	80.39
AN-WPN-3	6	50.33	96.00	45.67

a/ Each of these laboratory types serves only the course indicated.

b/ The maximum number of sections in house of any of these courses is 1.

inequality (15) is satisfied. During this time, an average of 195 contact hours per week are required.

Even though inequality (15) is not satisfied for every week of the year, one should not immediately conclude that it is infeasible to schedule the optimal number of classes of course 3. The schedule in Figure 3 shows that the three weeks where requirements exceed average availability occur when one class is completing the final week of the course and a new section is convening the same week. The computations leading to inequality (15) were made assuming a constant average demand for instructor resources throughout a course. In reality, the course syllabus will show peaks and valleys in the demand for contact hours upon a particular group of instructors as the course progresses. A block of instructors may therefore be required to teach less than the average number of contact hours during the first and last weeks of a course. If this is the case in this example, the imposition of six convenings of course 3 for three weeks of the year may not pose an intolerable hardship for the SINS Computer instructors, and thus the annual schedule may be considered feasible with respect to this resource.

If the average weekly contact hour load spread throughout the year is considered excessive, the school administration faces the choice of either teaching fewer than the optimal number of convenings of the course or obtaining additional instructors. In this case the single course taught by the SINS Computer block is convened 11 times

annually. This figure represents the lower bound on the number of convenings specified by BUPERS. If the present workload is excessive and no waiver of the lower bounds requirement can be obtained, then the strength of the SINS Computer block should be augmented.

The strength of the SINS Computer block is 11 instructors whose total annual block contact hour capacity was computed as 9,914 by applying equation (2) to data obtained from a questionnaire similar to Table I. From these figures an average individual contact hour capacity figure of 901.27 hours per year (or 18.03 hours per week) is obtained. This figure exceeds the norm of 756 contact hours per instructor obtained by applying equation (1). In order to satisfy inequality (15), the block should have a capacity to instruct an average of 198.28 contact hours per week. In reality, however, this figure can be exceeded for a certain number of weeks per year without detriment to the mission of the block if, for the remainder of the year, weekly schedules permit enough time for lesson preparation and other duties so that teaching demands can be met. The amount by which the value of 198.28 contact hours can be exceeded is a matter of judgment. Since only 3.28 average contact hours of slack per week are available when five convenings of course 3 per week are in progress, the school administration may well deem it advisable to augment the strength of the SINS Computer block--either by cross-training instructors of another specialty, if feasible, or by requesting an

augmentation of the instructor personnel allowance for this specialty.

Using the individual contact hour capacity of 901.27 hours per year per instructor, the addition of one more instructor would give the block a teaching capacity of 10,815 contact hours per year, or 216.3 contact hours per week. In this case, the addition of one man would still not satisfy inequality (15) during the three weeks when six classes of the SINS Technician course are in session. A "negative slack," averaging 17.7 hours per week, would occur. However, for the 47 weeks when five convenings are in progress, an average slack of 21.3 hours exists which should be ample to permit advance preparation for peak teaching loads. If the norm of 756 contact hours per year per instructor for navigation courses were used rather than the 901.27 value obtained from the questionnaire, we would find a requirement for 14 instructors rather than 12.

(2) SINS System Instructors. This block also instructs only the SINS Technician Mark 2 course. For the three weeks of the year when six convenings are "in house," inequality (15) is not satisfied since

$$(6)(44.2) = 265.2 > 229.76,$$

resulting in an average weekly net deficit of 35.44 contact hours. For the remaining 47 weeks when five convenings are in session, the average weekly contact hour requirement of 221.00 results in an average weekly slack of 8.76 hours. This figure may be sufficient to permit advance preparation

for peak workloads. The 12 men of this block have a total capacity of 11,488 contact hours per year according to data from the questionnaire. This results in a capacity of 957.3 contact hours per individual--well above the 756-hour BUPERS norm. Again, the addition of one instructor to this block may be necessary (in accordance with the questionnaire capacity figure) in order to meet the requirement to teach 11 sections of this course annually.

(3) SINS Conversion Instructors. The SINS Conversion instructors block teaches only course 4, the SINS Technician Mark II Conversion course. The maximum number of sections in house is two for three weeks of the year; otherwise one section of the course is in progress. When two sections are in progress, constraint (15) is violated, since an average of 160 contact hours per week is required while only an average of 98.5 hours are available. For the remainder of the year, an average of 80 contact hours per week are required. The three weeks of overload occur when one section is undergoing its final week of training and a second section is taking its first week of the course. Since this course is scheduled at its lower bound of six convenings per year, this requirement could be met by advance planning for peak teaching loads and reduction or suspension of collatoral duties during the three peak weeks.

(4) BQN-3 NAVAIDS Instructors. This block teaches courses 5 and 6, NAVAIDS Technician (Maintenance) and NAVAIDS Technician (Conversion). Peak teaching loads occur when the

schedule calls for one section of course 5 and seven sections of course 6 to be in progress simultaneously. In this situation inequality (15) is satisfied since

$$(46.67)(1) + (5.38)(7) = 46.67 + 37.66 = 84.33 < 146.12,$$

where 146.12 represents the average number of contact hours available per week for the block. Hence, the schedule may be considered feasible with respect to this resource.

(5) WPN-3 Instructors. This block serves only course 6. When the maximum number of sections (7) is in progress, inequality (15) is satisfied. Here

$$(6.73)(7) = 46.41 < 78.68,$$

where 78.68 is the average weekly contact hour availability.

(6) BRN-3 Instructors. This block also teaches only course 6. For the 27 weeks when seven sections of this course are undergoing instruction, inequality (15) is violated since

$$(20.19)(7) = 141.33 > 134.88,$$

where 134.88 is the average weekly contact hour availability. When six classes are taught simultaneously, the average weekly contact hour requirement is 121.64. The optimal annual number of convenings appearing on the schedule in Figure 3 is 12.5, but the specified lower bound for this course is only eight convenings per year. In this case, the school may avoid overtaxing the resources of the BRN-3 instructor block by reducing the number of course 6 convenings for the year. For example, if 12 classes are convened instead of 12.5, a schedule can be devised such that seven

sections will be in house simultaneously for only two weeks of the year and six will be in session for the remaining 48 weeks. For such a schedule, sufficient slack exists on the average throughout the year to meet the peak workload.

(7) <u>BSQ-2 (Conversion)/Mark XII Instructors</u>. This block serves courses 5 and 6. The heaviest teaching load for this block occurs when one convening of course 5 and seven classes of course 6 are in session. When this pattern occurs, inequality (15) is satisfied since

$$(11.67)(1) + (2.69)(7) = 11.67 + 18.83 = 30.50 < 78.68.$$

(8) <u>NAVDAC Type II Instructors</u>. This block serves courses 7 and 8--two curricula for NAVDAC Mark 2 technicians. The heaviest teaching load for the block occurs when two sections--one of each course--are in progress simultaneously. Under these circumstances inequality (15) is satisfied since the average weekly contact hour requirement of 13.34 is less than the average weekly availability of 22.02 contact hours.

(9) <u>NAVDAC (SDC), NAVDAC (General and NCC Instructors</u>. These blocks serve courses 7 and 8. An analysis of teaching load requirements for these three blocks shows that for the 36 weeks of the year that two sections (one of each course) are in progress simultaneously, causing the average weekly contact hour requirements to exceed the average availability. Specific results for this pattern are shown in Table XIII.

TABLE XIII. AVERAGE WEEKLY CONTACT HOUR REQUIREMENTS AND AVAILABILITIES FOR PEAK LOADS: NAVDAC (SDC), NAVDAC (GENERAL), AND NCC INSTRUCTORS

Block	Men	Y_7u_7	Y_8u_8	$\sum_7^8 Y_ju_j$	WCA_i	Average Weekly Slack
NAVDAC (SDC)	3	35.48	36.67	72.15	66.86	-5.29
NAVDAC (Gen.)	5	47.38	47.38	95.76	81.30	-14.36
NCC	2	12.14	12.14	24.28	22.02	-2.26

Although negative slack exists for these three blocks, the deficit does not exceed three contact hours per instructor per week for patterns where two courses are in progress simultaneously. However, to ascertain if these negative slacks for almost 75% of the year are acceptable, the work-load capacities of the individual instructors should be examined.

c. Priority Rules for Scheduling Convening Dates

In summary these tests for feasibility of an annual optimal convenings schedule for the six courses of Group Three show that ample laboratory resources exist to meet the demands of all patterns of the schedule. However, for several of the blocks of instructors, peak periods occurred when the average number of contact hours available to a particular block of instructors fell short of average weekly requirements.

In order to make a determination of the feasibility of the entire schedule in the face of peak demands,

a decision maker should first take note of the number of weeks per year that inequality (15) is not satisfied and the amount of the average weekly deficit in contact hours. If these quantities are considered small enough to preclude the overtaxing of a block of instructors with an excessive contact hour load for a substantial part of the year then the schedule should be adjudged feasible.

If, however, a balanced annual convenings schedule cannot be developed to preclude an excessive average weekly contact hour load for a substantial part of the year, the decision maker must either obtain additional instructors for the affected block or reduce the annual number of convenings of one or more of the courses taught by the block. If the number of convenings must be reduced, the following priority rules may aid the decision make in determining the order in which reductions should be made:

(1) Determine which courses taught by the block are currently scheduled above the number of convenings specified by higher authority. The course whose scheduled number of convenings exceeds its lower bound by the greatest amount is the first candidate for reduction.

(2) If a tie results in the previous step, the relative military worth of the courses converned should be ranked. Appropriate ranking criteria may be:

(a) officer courses take precedence over enlisted courses;

(b) conversion courses take precedence over initial courses.

The course with the lowest index of military worth would then be the first to be reduced.

(3) After determining the order in which the number of convenings should be reduced, remove one convening of the first course in this ordering and rearrange the annual schedule accordingly. If the revised schedule still results in prolonged peak demands above resource capacity, make further reductions and revisions, in the order set forth by steps (1) to (2), until a schedule with acceptable peak demands emerges, or else the number of convenings of all courses is reduced to the lower bound values.

If, in revising the annual schedule, all courses sharing a resource are reduced to their lower bounds and the peak demands on that resource are considered excessive over a long period of time, then the following actions may be appropriate:

(a) re-evaluate course content requirements in terms of lecture and lab hours with respect to this resource;

(b) re-examine workload data for instructors to ascertain if the annual contact hour availability of a block can be increased by reducing collateral duty requirements or revising preparation standards;

(c) transfer additional personnel into those instructor blocks with substantial average contact hour deficits;

(d) request a reduction in annual lower bound requirements for the course(s) concerned as a last resort.

IV. DISCUSSION AND EXTENSIONS

A. PARAMETRIC STUDIES

In addition to the principal output of the model of Chapter II, i.e., an optimal number of convenings of each of a specified set of courses over a given time period, other information of a more analytic nature is available from the linear programming techniques. This information provides insight into the sensitivity of the model to changes in resource utilization and constraints. By use of parametric studies, which can be easily done with the Mathematical Programming System (MPS), it is possible to determine the range of course convenings per year which can be obtained by varying the value of a given constraint with all other constraints held constant.

In the Navigation Division example, the dual activity values obtained by solving the LP represent the number of additional course convenings which can be obtained by relaxing the associated constraint by one unit. In general, the dual activity indicates the marginal rate of change in the objective function which can be obtained if a small change in a coefficient of a constraint is considered. Table XIV lists the constraints with non-zero dual activity values which are obtained from the solution of the annual convenings model. The negative values of the dual activity for the NT3

Lab Type and the Navigation Officer Instructors Block indicate that a higher value of the objective function will result if the constraint is relaxed. For example, the objective function could be increased by 0.023 convenings per year if the availability of the NT3 lab type is increased by one hour per year. Similarly, a positive value of the dual activity indicates that the objective function value will be reduced if the constraint is increased by one unit. For example, from Table XIV, we would find that raising the lower bound of the annual convenings of course 3 by one convening will result in the reduction of the objective function value by 5.273 convenings per year (all other constraints held constant).

TABLE XIV. CONSTRAINTS WITH NON-ZERO DUAL ACTIVITY (ANNUAL MODEL)

Constraint Name	Constraint Value	Dual Activity
Lab Type NT3	4800 hr/yr	-0.023
Navigation Officer Instructors	2602 hr/yr	-0.005
Lower Bound on convenings of course 3 (SINS Technician, Mark 2)	11 classes/yr	5.273
Lower Bound on convenings of course 4 (SINS Technician, Mark 2, Conversion)	6 classes/yr	3.091

MPS/360 provides a routine called PARARHS to perform parametric programming on any of the constraint values. Parametric studies using PARARHS were made of the RHS

constraints listed in Table XIV. The results of these parametric studies are shown in Figures 4 through 7.

Figure 4 illustrates the results of varying the annual availability of Lab Type NT3, in terms of changes in the value of the objective function and the number of convenings of courses 3, 4, 5 and 6. Originally, Lab Type NT3 had an availability of 4800 hours per year. From the solution of the LP model we found that the school had a capacity to convene 49.1 courses of all types annually, including 11.0, 6.0, 3.0, and 12.5 convenings of courses 3, 4, 5 and 6 respectively. Using PARARHS, we found that the dual activity value of -0.023 represented the incremental number of annual convenings of all courses which could be obtained by varying the value of the NT3 constraint by one unit within the range of 4600 to 6578 hours of availability per year. Below 4600 hours per year, no feasible solution of the LP exists. At 4600 hours of availability, the objective function had a value of 44.6 convenings per year, while courses 3, 4, 5 and 6 could be convened 11, 6, 3 and 8 times per year respectively. As availability of the NT3 Lab Type was increased, we found a linear increase in the value of the objective function until the figure of 6578 hours per year was reached. At this point, the objective function had reached its maximum obtainable value of 86.7 convenings per year, while the maximum attainable number of convenings for the individual courses served by the lab type was 11.1, 6.8, 39.3, and 12.8 for courses 3, 4, 5 and 6 respectively.

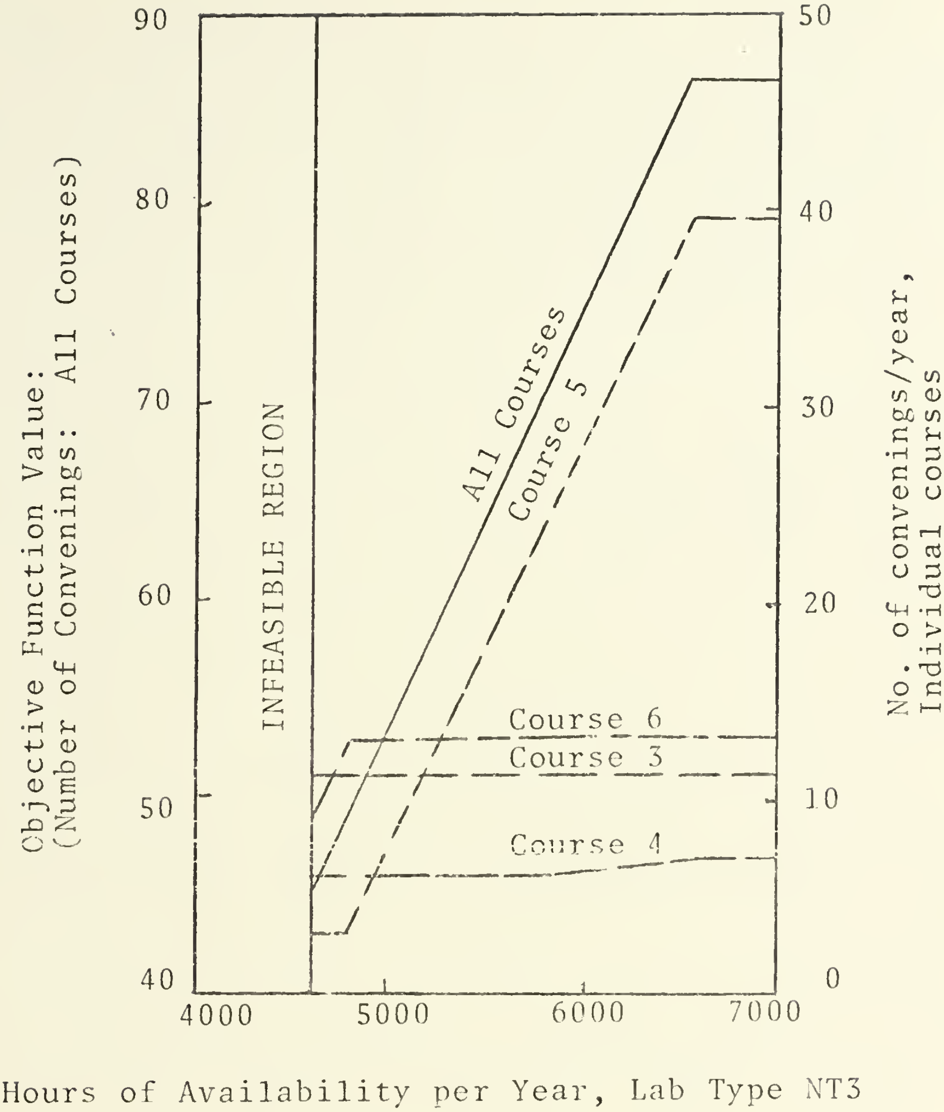


Figure 4. Parametric Study of Varying the Annual Availability of Lab Type NT3

A similar interpretation may be given to Figures 5, 6 and 7. The four constraints illustrated herein were the most applicable to parametric studies of all the constraints in the Navigation Division example, since all other constraints had zero or negligible values of the dual activity at optimum.

B. FLUCTUATIONS IN STUDENT INPUT

The solution to the annual convenings model will indicate how many sections of each course can be convened at optimum; however, this solution does not take into account fluctuations in student availability for entry into the classes throughout the year. These fluctuations in student input are the result of a number of random variables such as the enlistment rate of each type of trainee, and the dropout rate at prerequisite schools. Deterministic factors, such as the schedule of courses attended by the trainees prior to their assignment to the Class B school, also cause fluctuations in student loading. There is a need for further refinement of the model of Chapter II to take specific account of these fluctuations.

An expected value of the number of students trained per year in a given course could be estimated as follows:

1. Review historical data on the annual number of trainees entering the course in past years, and compare these figures with the product of class capacity and the number of convenings that actually occurred annually during the period under review. The ratio of trainee entrants to the sum of class

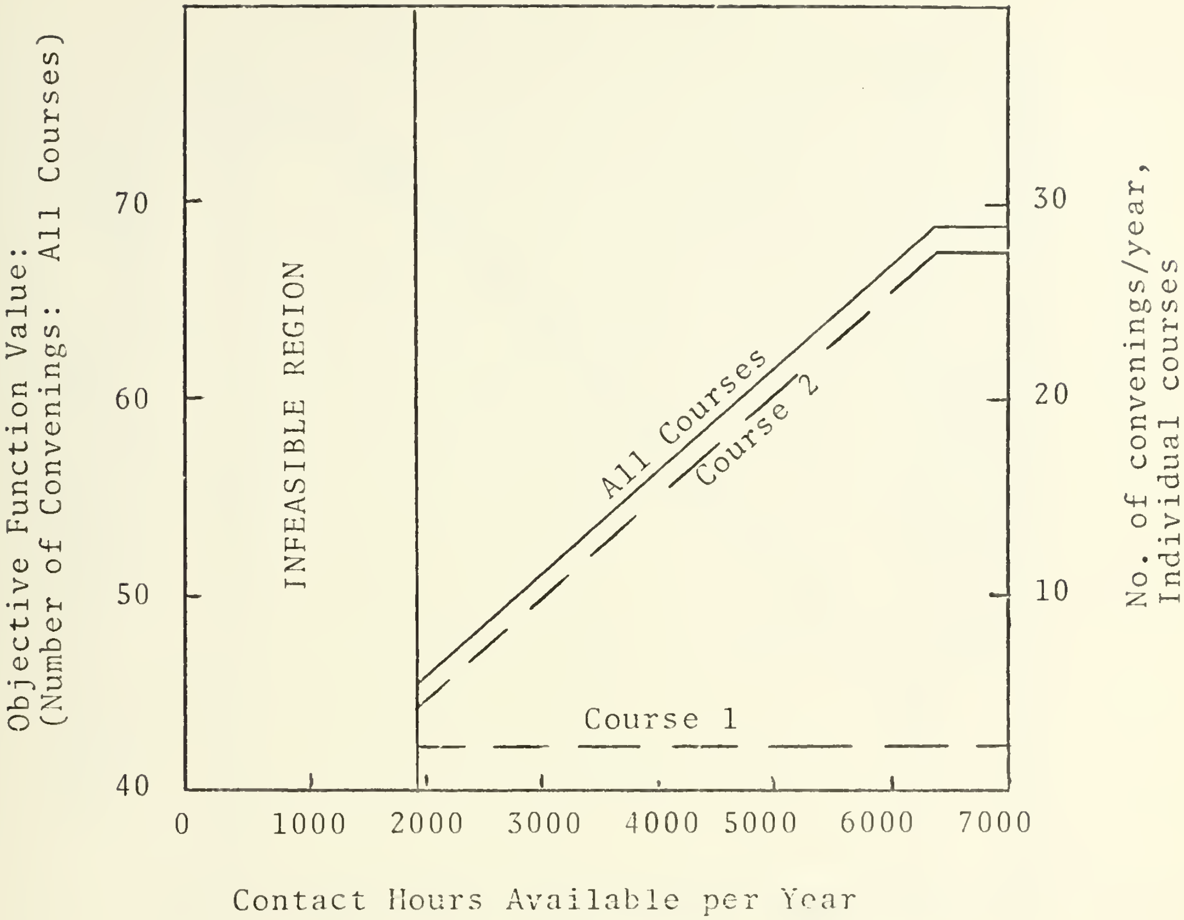


Figure 5. Parametric Study of Varying the Annual Contact Hour Availability of the Navigation Officer Instructors (POSEIDON)

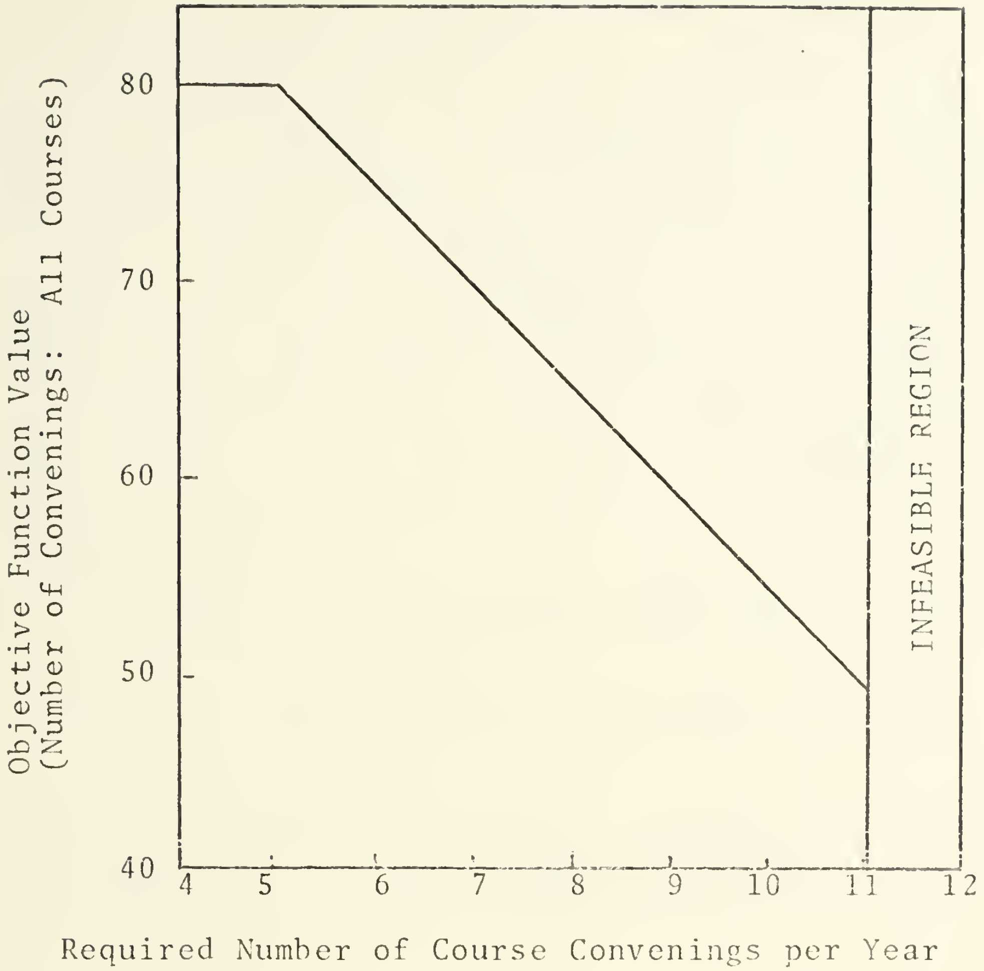


Figure 6. Parametric Study of Varying the Lower Bounds Constraint on the Annual Number of Convenings of the SINS Technician Mark 2 Course

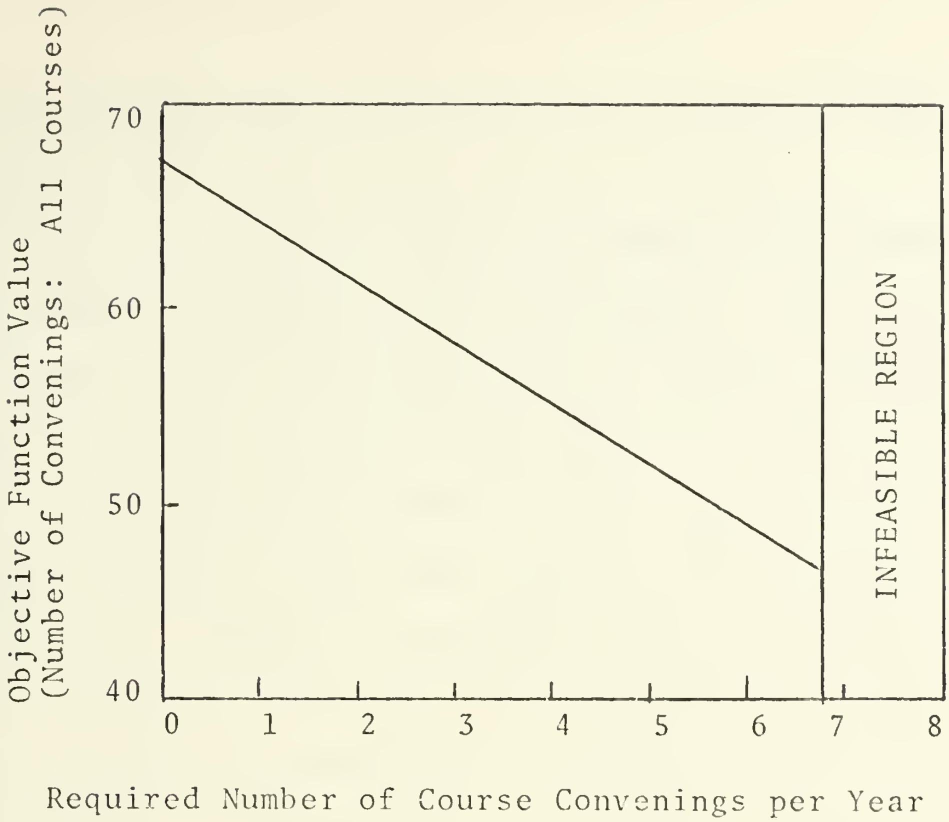


Figure 7. Parametric Study of Varying the Lower Bounds Constraint on the Annual Number of Convenings of the SINS Technician Mark 2 Course (Conversion)

capacities for a year will yield a percentage of class capacity filled.

2. Multiply the optimal annual number of convenings of the course by the product of class capacity and expected percentage of class capacity filled to obtain the expected number of trainees entering the particular course annually.

It is recognized that an annual value of "percentage of class capacity filled" may depend on other factors besides past history. Trends in enlistment rates and reenlistment rates, as well as dropout rates from predecessor training schools, should be considered. In order to forecast seasonal variations in percentages of class capacity filled, it is necessary to obtain historical and trend data on a seasonal basis. Using such data, seasonal adjustments may be applied to the expected percentage of class capacities filled for classes commencing at different times of the year when a schedule based on the annual convenings optimal model is used as a planning tool.

C. ECONOMIC INPUT-OUTPUT ANALYSIS

This study has focused upon finding a methodology to maximize the number of convenings of a set of courses a school can achieve over a given period of time. The principal constraints considered in the formulation of the model were the availability of instructor resources, laboratory resources of various types, and classrooms. Other constraints may also have a bearing on this problem. For example, the

number of administrative, supervisory and maintenance personnel assigned directly to the training department to provide support to instruction will need to be varied with changes in the level of student enrollments required during a given period of time. Further, large variations in student loading will affect the level of the various supporting activities throughout the school which are required for different sizes of student bodies. Drastic increases in the number of students attending a training school will require the provision of additional berthing, dining, administrative, and recreational facilities on the base, as well as increases in the amount of laboratory facilities and the number of instructors required to support an increased course load. In determining the required level of resources of all types to support varying numbers of students, an economic input-output model of the entire school seems more appropriate. While such models have been prepared for institutions of higher learning, e.g., [Ref. 1], it appears that no such studies have been made of Navy enlisted training schools such as GMS Dam Neck.

D. DETAILED SCHEDULING PROCEDURES

This study presented a method to schedule an optimal number of course convenings, with the optima obtained from an LP model. This scheduling procedure considered only the gross requirements of the courses, namely the specified course length, and the number of instructor contact hours and

laboratory hours required in each phase of a given course. The sequencing of individual topics within a phase and the sequential relationships among the various phases comprising each course are not explicitly considered in the optimizing model. Hence, the model as given should be refined to take account of any sequencing requirements for topics and phases of instruction.

Procedures were proposed in Chapter III for developing an annual schedule based on the annual convenings linear programming model, and for testing such a schedule for feasibility. These procedures could be modified to develop an annual convenings schedule based on the actual sequences of topics prescribed by course syllabi. Then this schedule could be tested for feasibility on a daily basis, by developing a method, similar to that of Chapter III, for determining if average daily resource capacities could accommodate average daily resource demands.

E. AVOIDING INTERFERENCE IN LABORATORY SCHEDULING

Although sufficient laboratory space and equipment may be available to permit the convening of a specified number of courses at a school during a given time period, some interference between diverse classes using the same laboratory rooms does occur.

The FBM Schools laboratories provide complete operating systems, with all of their associated equipments, for the POSEIDON and POLARIS weapons systems. Actual shipboard

equipment configurations are duplicated as much as possible. Aboard an SSBN, personnel of different ratings operate and maintain diverse but associated components in the same compartment. However, the same configuration in a single room in a training facility may result in a Babel of confusion when two or more classes are undergoing instruction on different types of equipment simultaneously. The LP model of this study did not include this interference problem.

It appears likely that any method which reduces interference would come at the price of reducing the optimal number of the affected courses that could be convened during a year. The model presented in this study dealt with laboratory types as a constraint, "types" meaning rooms with identical types of equipments installed therein. A finer measure of the availability of laboratory resources could be obtained by inventorying the installed equipments in the laboratories and computing the availability of each equipment over a specified time period. Similarly, for the same time period, the requirements for one convening of each course could be obtained in terms of hours of utilization of each type of laboratory equipment. The laboratory constraints could then be rewritten for the basic model in terms of required versus available equipment hours for each category.

F. CLASSROOM CAPACITY

Classroom capacity is one of the constraints that should be taken into account in using the annual convenings model

of Chapter II. Although this constraint was not binding for the example presented in this study, we noted that, even when no shortage of classrooms is likely, a course cannot be scheduled in a room with inadequate seating capacity. On the other hand, it seems logical to assess a penalty for scheduling it in a room too large if the school administration desires to minimize idle space. Thus, in preparing a detailed scheduling model for the school, one could construct cost multiplication factors to reflect quantitatively these utilization requirements. An illustration of these ideas is shown in Table XIV. An entry of 1.0 in this table would indicate that the appropriate sized classroom has been assigned to a given section. The entries of 1.2 and 1.5 would indicate that a penalty has been assessed for assigning a relatively small section to too large a classroom. A penalty of infinity would positively preclude the assignment of too large a section to a small classroom. A similar table could be constructed to preclude or reduce interference among sections using a particular laboratory room. Reference 6 discusses this problem in detail.

TABLE XV. COST MULTIPLICATION FACTORS TO ACHIEVE EFFICIENT CLASSROOM UTILIZATION

Course (Section)	Classroom Size			
	1	2	3	Rank
Size	10	11-20	21-30	Capacity
1. (< 10 students)	1.0	1.2	1.5	
2. (11-20 students)	∞	1.0	1.2	
3. (21-30 students)	∞	∞	1.0	

V. SUMMARY AND CONCLUSION

This study addressed the problem of obtaining a maximum flow of student sections through a training school, subject to various resource constraints. The problem was approached in two phases: (1) maximizing the total number of convenings of courses taught by the school annually; and (2) constructing a balanced annual schedule of class convening dates from the results of the first phase.

A linear programming model was developed for the Phase I problem. The principal constraints were identified and expressed as follows:

(1) curricular requirements for each course in terms of the number of instructor-student contact hours and laboratory hours required for one convening;

(2) instructor contact hours available annually (by type);

(3) laboratory hours available annually (by type);

(4) classroom hours available annually (by type);

(5) requirements for a specified number of graduating classes over time expressed as a lower bound on the number of convenings of each course per year.

Using the optimal solution to the Phase I problem, a procedure for scheduling class convening dates for these optimal numbers was proposed. This procedure attempts to achieve a balanced or nearly constant demand for resources

throughout the year. A heuristic method for testing the schedule for feasibility has been presented which shows a schedule to be feasible when the average number of classes called for by that schedule can be in progress without overtaxing available resources at any time. In the event that convening the optimal number of classes results in unacceptably high demands for resources, priority rules are suggested to ensure that the most essential classes are given first consideration in the scheduling process.

BIBLIOGRAPHY

1. Abbey, D. L., An Economic Model of the Naval Postgraduate School, (Naval Postgraduate School, 1968).

2. Bureau of Naval Personnel Instruction 1510.105, Subject: Procedures for Determining Numbers of Instructors for Navy Enlisted Schools, (17 November 1967).

3. Gass, Saul I., Linear Programming, (New York: McGraw-Hill, 1964).

4. General Electric Company, Linear Programming Methods, Publication 811248A, (Bethesda, Maryland: General Electric Company, Information Services Department, February, 1970).

5. International Business Machines Corporation, Mathematical Programming System/360 (360A-CO-14X), Linear and Separable Programming--User's Manual, Publication H20-0476-1 (White Plains, N. Y.: IBM Corpiration, 1968).

6. Schoeman, Milton, "A Class Scheduling Algorithm," Chapter V, Final Report, Project Generalized University Model, Phase III, (Austin: University of Texas, Graduate School of Business, November, 1969).

7. U. S. Naval Guided Missiles School, Dam Neck, Schedule of Polaris and Poseidon Courses for Fiscal Year 70 and Fiscal Year 71 at Naval Guided Missiles School, Dam Neck, Virginia Beach, Virginia (undated).

8. U. S. Naval Guided Missiles School, Dam Neck Letter Serial 1807 to Bureau of Naval Personnel, Subject: Inventory of number of instructors required for Navy Enlisted Schools, submission of, 2 August 1969.

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13. ABSTRACT

The problem of determining the capacity of a facility, such as the Fleet Ballistic Missile School, to train sections of students attending numerous distinct courses was considered as an optimizing problem, approachable in two phases. In the first phase a linear programming model was developed for determining the maximum number of courses and the optimal mix of these courses which the school can convene in one year. This model incorporates resource constraints, course content requirements, and the requirement to graduate a specified number of trainees over time. In the second phase, criteria were developed to sequence the Phase I optimal number of convenings of each course into an annual schedule. A heuristic approach was presented to test such a schedule for feasibility.

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